TITLE: Dynamics of Electrons at Intersubband Excitation in Asymmetric Tunnel-Coupled Quantum Well Structure

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Dynamics of electrons at intersubband excitation in asymmetric tunnel-coupled quantum well structure

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Abstract. We present investigations of the intersubband electron dynamics in asymmetric tunnel-coupled GaAs/AlGaAs quantum wells. The study is performed by time resolved pump and probe experiments. Temporal evolution of the bleaching signals has biexponential behaviour. In addition to the time of the relaxation into the ground state with LO-phonon emission a second long decay time depending on transition energy and temperature is observed. We associate the second recovery time with transitions between confined Γ-state of quantum wells and states in the barriers including X_Z-states which appear due to high content of Al. The influence of the transitions between subbands with energy separation less than optical phonon energy on the relaxation processes is also discussed.

Introduction

The asymmetric tunnel-coupled quantum well (ATCQW) structures attracted considerable attention because of possibility of lasing [1] and modulation of MIR radiation [2] due to intersubband transitions. The knowledge of the electron dynamics is very essential to improve the properties of these devices. In the double quantum well structures the electron dynamics is very complicated due to a large number of the levels. There are a lot of methods for measurement of electron relaxation time, for example intersubband saturation method [3] or excited-state induced absorption spectroscopy technique [4]. However, these methods have the some limitations, as it is necessary to know the homogeneous broadening of the absorption line. Generally the intersubband line has an inhomogeneous broadening [5]. The investigations by pump and probe techniques allow us to measure directly the temporal evolution of the transmission spectra after excitation, and to determine the respective relaxation time. In this work we study the relaxation processes in ATCQW structure by the time and frequency resolved pump and probe spectroscopy.

1. Sample structure and experimental method

The studied modulated doped structure was grown by MBE on semiinsulated GaAs (100) substrate. The widths of the first GaAs quantum well (QW) and the second $Al_{0.1}Ga_{0.9}As$ well are 5 nm and 8.3 nm respectively. The width of the tunnel-transparent $Al_{0.42}Ga_{0.58}As$ barrier between them is 2 nm. The width of $Al_{0.42}Ga_{0.58}As$ barrier between pairs of QWs is 25 nm. The center of 25 nm barrier was doped by Si. The surface electron concentrations is $N_S = 5 \times 10^{11}$ cm^{-2}.

The sample is prepared in a prism geometry with one reflection at 65° at the plane of QW layers to get strong absorption signals.

The relaxation measurements are performed by a Nd:glass laser system of 8 Hz repetition rate with two travelling wave IR dye lasers and two difference frequency mixing stages.

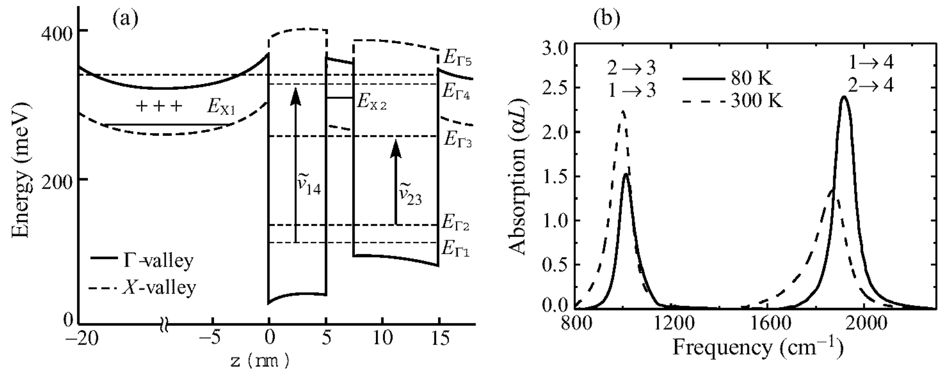

Fig. 1. (a) The potential profile of the structure and calculated energy levels; (b) equilibrium intersubband absorption spectra at different temperatures.

The system generates two light pulses of 2 ps duration with a spectral width of 10 cm^{-1} independently tunable between 800 cm^{-1} and 2500 cm^{-1}. One of the two infrared pulses excites electrons at a good defined pump frequency $\tilde{\nu}_{\mathrm{pump}}$ from the lower states to the excited subbands. The subsequent time resolved change of the intersubband absorption is measured by the second weaker infrared pulse at any probe frequency $\tilde{\nu}_{\mathrm{probe}}$.

2. Results and discussion

Due to high contents of Al in the barriers it is necessary to consider the effect of $\Gamma - X$ mixing [6]. The potential profile of Γ and X valleys and energy levels in the structure are presented in Fig. 1(a). The states with the energy $E_{\Gamma1}$, $E_{\Gamma4}$ and $E_{\Gamma2}$, $E_{\Gamma3}$ are generated by the narrow and wide wells respectively. It leads in particular to the different localization of wave functions. Wave functions Ψ_1 and Ψ_2 are localized mainly within the first and the second well respectively. Moreover, optical dipole matrix elements strongly differ: $Z_{14} = 1.13$ nm, $Z_{24} = 0.7$ nm and $Z_{13} = 0.4$ nm, $Z_{23} = 2.27$ nm. The greatest contribution to intersubband absorption is made by transitions between levels originated from the same well. One more state $E_{\Gamma5}$ can appear in QW, which is formed in wide barrier due to space charge effect.

The $Al_{0.42}Ga_{0.58}As$ layers are quantum wells for X-electrons, the thin barrier contains one confined E_{X2}-state. There are also quantum-confined states for X-electrons in thick barrier dividing the pairs of QWs.

The absorption spectra measured with a BRUKER FTIR spectrometer contain two absorption bands (Fig. 1(b)) having at liquid nitrogen temperature the peak frequencies of 1010 cm^{-1} and 1915 cm^{-1}. With increase of temperature the typical redshift and broadening of absorption lines are observed. At room temperature the peak frequencies are 1000 cm^{-1} and 1870 cm^{-1} respectively.

The investigation of the temporal evolution of the transmission spectra at different pump and probe frequencies in resonance of transitions at 300 K are presented in Fig.2. The results were also obtained at other temperatures. Pump and probe measurements at the same pump and probe frequencies show the biexponential behaviour of carrier relaxation. The fast relaxation time (1.2 ps) is almost independent of pump frequencies and temperature, whereas the long term decay strongly depends on these factors. Besides when pump and probe frequencies are located in the center of the different absorption bands mainly the long relaxation time can be observed. We connect the fast relaxation processes with scattering

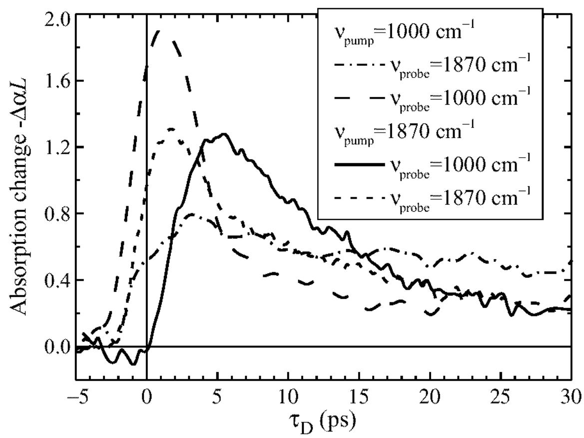

Fig. 2. Time resolved absorption change at 300 K after excitation at different pump frequencies.

of the electrons into the ground state due to LO-phonon emission. The nature of the slow component will be discussed below. We can assume that the pump pulse excites the carriers only within the one well, because the transitions between levels originated from the same well give the main contribution to the intersubband absorption. However, one can see, that when the pump frequency lies in maximum of long-wavelength absorption band there is also the bleaching of the short-wavelength absorption band and vice versa. This bleaching comes from the electron redistribution among the first and second subbands. In spite of small distance between $E_{\Gamma 1}$ and $E_{\Gamma 2}$ ($\sim$10 meV) such redistribution becames possible due to LO-phonon scattering at room temperature with time less than 1 ps. This time (5 ps) is longer at 80 K. At this temperature LO-phonon scattering is suppressed and a scattering on impurities and acoustic phonons can play a key role.

In order to understand the strong dependence of long recovery time on pump frequencies let us consider the potential structure of ATCQW. The high contents of Al in barrier leads to appearing the QWs for X-electrons and to coupling the Γ- and X-states. It makes possible a scattering between Γ- and X-states. An intervalley $\Gamma - X$ scattering time is directly proportional to the overlap integral of wave functions [7] and is about 1 ps. Excitation at $\tilde{\nu}_{14}$ or $\tilde{\nu}_{23}$ leads to filling of these states that are mixed with the X-states of tunnel-transparent barrier and barriers between pairs. An intervalley scattering into the X-states takes place. Electrons return from X-valley to ground subband with the large back scattering time (40 ps) because the density of states in Γ-valley is lower compared to the one in X-valley. At excitation between $E_{\Gamma 1}$ and $E_{\Gamma 4}$ levels the real space transfer into confined barrier states can play the main role. This can determine a long decay time (15–20 ps). Similar mechanism was considered in [8].

3. Conclusion

The dynamics of intersubband transitions in asymmetric tunnel-coupled quantum well structure is investigated by time resolved pump and probe experiments. The biexponential behaviour of absortpion recovery is found. The fast time is responsible for intersubband relaxation of the electrons due to emission of LO-phonons. The long term decay time comes from the intervalley $\Gamma - X$ scattering and real space transfer in confined barrier states. The effect of interwell transitions on intersubband relaxation is also considered.

Acknowledgements

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